DEVELOPMENT AND TESTING OF A WATER MANAGEMENT MODEL (WATRCOM): FIELD TESTING

J. E. Parsons, C. W. Doty, R. W. Skaggs
ASSOC. MEMBER ASAE — FELLOW ASAE

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ABSTRACT

Water table observations from the 1000 ha watershed of Mitchell Creek near Tarboro, NC, were used to field test the water management model, WATRCOM. Soil properties and channel boundary conditions from three sections of the watershed along with weather data from years 1983 and 1984 were used to simulate the hydrology of the area with and without channel water level control. Six transects containing 27 water table observation wells were selected for testing. All simulations were based on measured field parameters and no calibration simulations were made to optimize parameters to fit observed data. A total of 14,000 daily water table observations were compared with simulated data. The root mean square error in simulated water tables at each well ranged from 0.05 to 0.24 m. When the data were pooled by section, the root mean square error ranged from 0.10 to 0.17 m.

KEYWORDS. Drainage, Watershed, Channels, Hydrologic modeling, Testing, Water table.

INTRODUCTION

In 1985, the total area of rural land drained in the United States was estimated to be 45 million ha (Pavelis, 1987). Wenberg and Gerald (1982) reported that approximately 3.4 million ha of drained sandy loam and organic soils are in the South Atlantic Coastal Plain. Drainage outlets for much of this land is provided by organized Drainage Districts. Although the definition and organizational structure varies from state to state, these districts provide a unified approach among landowners for implementing drainage practices.

Water management in drainage districts in the Southeast is complicated by periods of excessive rainfall and drought. Deep drainage channels are needed to provide adequate drainage during excessive rainfall to prevent flooding and crop damage. These same channels contribute to the severity of drought periods by lowering water tables in lands near the channels. Low channel flow occurs naturally during dry periods, so the channels are not reliable water supplies for irrigation. Channel water level control can be used effectively to reduce some of these negatives. The design and installation of these projects is costly. The water management simulation model WATRCOM was developed to assist in a-priori evaluation of the design and management of channel water level control in drainage districts in the southeastern United States. The development of WATRCOM is described in detail by Parsons (1987) and Parsons et al. (1991).

This article presents the results of field tests of the reliability of the water management model, WATRCOM. The model was developed to predict the effects of channel water level control on soil water conditions and water conservation in poorly drained watersheds. It is capable of considering variations in soils, crops, water management, and farming practices over the watershed. The model also considers irregular drainage networks including parallel and intersecting channels. The 1000 ha research site consisting of a wide range of shallow water table, sandy soils is located near Conetoe, NC (Doty et al., 1984b). A channel water level control structure was installed in 1982 on Mitchell Creek, the main drainage channel for the experimental watershed. Three areas within the research site were selected for the field tests. Input data sets for each of the areas were constructed using field and laboratory data from the areas. The water table response to controlled and uncontrolled channel water conditions as well as rainfall, evapotranspiration, and other hydrologic variables was simulated for each area and compared to measured water table elevations at 27 locations in the watershed. The objective of this article is to present results of those comparisons for 1983 and 1984 and to evaluate the reliability of WATRCOM predictions of soil water conditions on a watershed scale.

WATERSHED DESCRIPTION

EXPERIMENTAL SITE

A field research project to evaluate the effect of channel water level control on conservation and management of water resources in agricultural drainage districts was conducted in eastern North Carolina from 1979-1985. The project area was located near Conetoe, NC, in Pitt and Edgecombe counties. The research site included a 4.5 km section of Mitchell Creek located in the Conetoe Creek Watershed (fig. 1). The 1000 ha area is nearly flat with a maximum elevation difference of 3.0 m. The soils in the

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The authors are **John E. Parsons**, Assistant Professor, North Carolina State University, Biological and Agricultural Engineering Dept., Raleigh (formerly Agricultural Engineer, USDA-ARS, Florence, SC); **Coy W. Doty**, Agricultural Engineer (Deceased), USDA-ARS, Florence, SC; and **R. Wayne Skaggs**, Professor, Biological and Agricultural Engineering Dept., North Carolina State University, Raleigh.

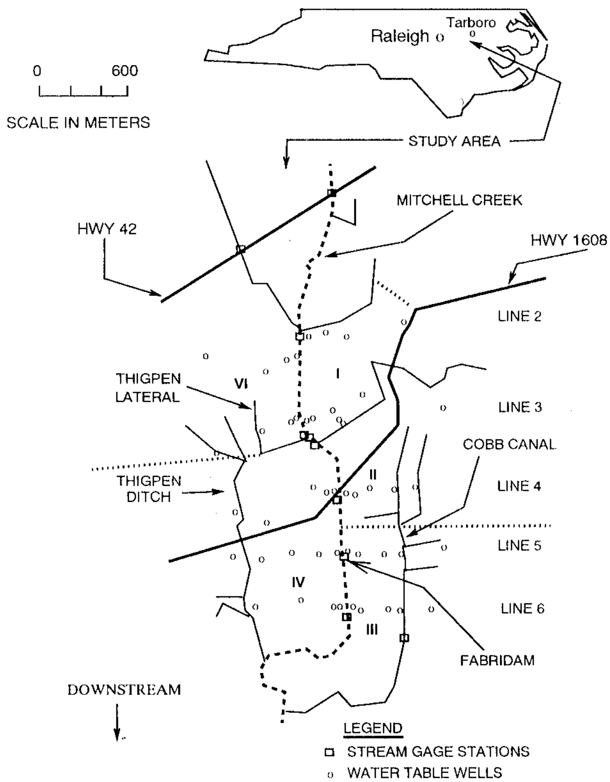

Figure 1–Map of the study site located on Mitchell Creek in the Conetoe Creek Drainage District.

area range from poorly drained to somewhat excessively drained. They were formed in sandy, alluvial, and marine sediments. The area is underlain by a coarse sandy aquifer between 1.4 and 2.4 m from the soil surface. A layer of blue consistent clay occurs at depths ranging from 4 to 8 m below the soil surface.

Soil water table and channel water levels were monitored continuously at selected points throughout the Mitchell Creek research area (Doty et al., 1984a, 1985). There were 60 water table observation wells located in six lines perpendicular to Mitchell Creek and 12 stream water level stations (fig. 1). For this analysis, the watershed was divided into six sections (labeled I through VI in fig. 1) using natural and constructed drainage channels as boundaries. A water-inflatable, channel control structure was installed in Mitchell Creek between sections III and IV in 1982. The structure was used to periodically control the water level in Mitchell Creek to reduce overdrainage in the deep sandy soils, conserve water, and improve drainage water quality (Doty et al., 1986).

SOILS

A detailed soil survey was conducted by USDA-Soil Conservation Service. The primary soil series in the area are summarized in Table 1. Undisturbed soil cores were collected for a range of depths as reported by Badr (1983) and Parsons (1987). The drainage branch of the soil water characteristic and the vertical saturated hydraulic conductivity were measured. These data were used to calculate the relationships between drainage volume, drainable porosity, Green-Ampt infiltration parameters, and water table depth. The unsaturated hydraulic conductivity

TABLE 1. Soil types and corresponding map symbols from the United States Department of Agriculture, Soil Conservation Service (USDA-SCS, 1974 and 1979)

Map Symbol	Soil Series and Subgroup	
821	Cape Fear loam	*(Typic Umbraquults)*
816	Portsmouth loam	*(Typic Umbraquults)*
812	Portsmouth sandy loam (coarse loamy variant)	*(Typic Umbraquults)*
564	Wahee sandy loam	*(Aeric Ochraquults)*
544	Altavista sandy loam	*(Aquic Hapludults)*
543	Altavista sandy loam (coarse loamy variant)	*(Aquic Hapludults)*
371	Conetoe loamy sand	*(Arenic Hapludults)*
352	State sandy loam	*(Typic Hapludults)*
46	Augusta sandy loam	*(Aeric Ochraquults)*

function was calculated by the Millington and Quirk (1960) method and used to determine the relationship between the maximum steady state upward flux and water table depth (Badr, 1983).

Lateral saturated hydraulic conductivity measurements were made in numerous locations throughout the research area. Badr (1983) reported 13 measurements made at the time of the well installations with the well pump-in test procedure. Additional auger hole tests (van Beers, 1970) were performed at 103 locations and are described in detail by Parsons (1987). All auger hole tests were conducted for water table depths greater than 0.75 m; the soil horizons consisted of medium to coarse sands.

WEATHER DATA

Rainfall, air temperature, and other meteorological variables were recorded continuously from 1979-1986 with chart recorders and a data acquisition system. These records were used to determine potential evapotranspiration and rainfall intensity needed in the model. Potential evapotranspiration was computed using the Jensen-Haise method (Jensen, 1974). The coefficients were estimated using 29 years, 1950-1978, of daily maximum and minimum air temperatures from Wilson, NC. The equation is:

$$PET = \left(3.263 * 10^{-4} * T + 0.106 \right) R_s \qquad (1)$$

where

PET = potential evapotranspiration (mm),
T = daily average air temperature (°C),
R_S = solar radiation for the day (langleys).

FIELD TEST PROCEDURE

Three areas within the Mitchell Creek portion of the drainage district were chosen for the field tests; section I, the combined sections II and III, section IV (fig. 1). The Fabridam is between the combined section, II and III, and section IV on Mitchell Creek. Section I is upstream from the dam.

The channel boundary conditions were determined from the channel water level recorders within each section. Daily averages of the observed channel water levels at each stream stage location were used. Table 2 summarizes by month the measured daily rainfall and estimates of PET for

TABLE 2. Monthly summary of the weather data for 1983 and 1984

Month	1983 PET*	1983 Rain	1984 PET*	1984 Rain
	----------mm----------		----------mm----------	
1	18	61	15	63
2	23	156	37	134
3	53	128	56	118
4	78	67	79	88
5	132	93	136	183
6	148	58	172	58
7	177	61	136	250
8	155	76	145	87
9	99	133	96	124
10	64	49	71	8
11	36	78	32	24
12	19	174	27	37

* PET determined with Jensen-Haise Method.

the test years, 1983 and 1984. The primary crops grown on the watershed were corn, soybean, and peanuts.

The model was tested by comparing average daily simulated field water table elevations to observed values. Predicted and measured water table elevations at each observation well were plotted for both 1983 and 1984. The first test of fit was visual comparison of the simulated and observed results. Next, the average absolute error was computed by:

$$AERR = \left[\sum_{i=1}^{NDAY} ABS(PWTE_i - OWTE_i) \right] / NDAY \quad (2)$$

where

AERR = average daily absolute error (m),
NDAY = number of days,
ABS = absolute value function,
i = day index,
$PWTE_i$ = predicted water table elevation on the *ith* day,
$OWTE_i$ = observed water table elevation on the *ith* day.

The average absolute errors were compared by observation well, transect (or line of wells), and section. The root mean square error (RMSE) was also computed for each well, transect, and section as:

$$RMSE = \left\{ \left[\sum_{i=1}^{NDAY} (PWTE_i - OWTE_i)^2 \right] / NDAY \right\}^{1/2} \quad (3)$$

The correlation coefficient between the observed and simulated water table elevations was also computed and used to evaluate model performance. The Pearson product-moment correlation coefficient, r, (James and Burges, 1982) was computed as:

$$r = \sum_{i=1}^{NDAY} \left[(OWTE_i - AO)(PWTE_i - AS) \right] / (S_O \, S_S \, NDAY) \quad (4)$$

where

AO = average of the observed water table elevations,
AS = average of the simulated water table elevations,
S_O = standard deviation of the observed water table elevations,
S_S = standard deviation of the simulated water table elevations.

RESULTS OF THE FIELD TESTS

SECTION I

The finite element grid for the simulations of Section I is shown in figure 2. This section is bordered by the main drainage channel, Mitchell Creek, the lateral ditch, M4, and two farm ditches. Daily stream water levels were determined on each boundary for 1983 and 1984. Figure 3 shows the subregions used to specify the soil parameters. The effective saturated conductivities and the soil types for each subregion are presented in Table 3. The conductivities were determined using the auger hole test at sites in this section. These represent effective values for the soil horizon depths greater than 0.75 m, where textures were generally medium and coarse sands.

Water table elevations were measured at six locations in section I. Four of the water table elevation wells are on well line 3 and perpendicular to Mitchell Creek. The remaining two wells are on a transect perpendicular to lateral ditch, M4 (fig. 2). Figure 4 shows the cross-section of the transect along well line 3 with the initial water table profile for the 1983 tests (on 1 February, day 32). The

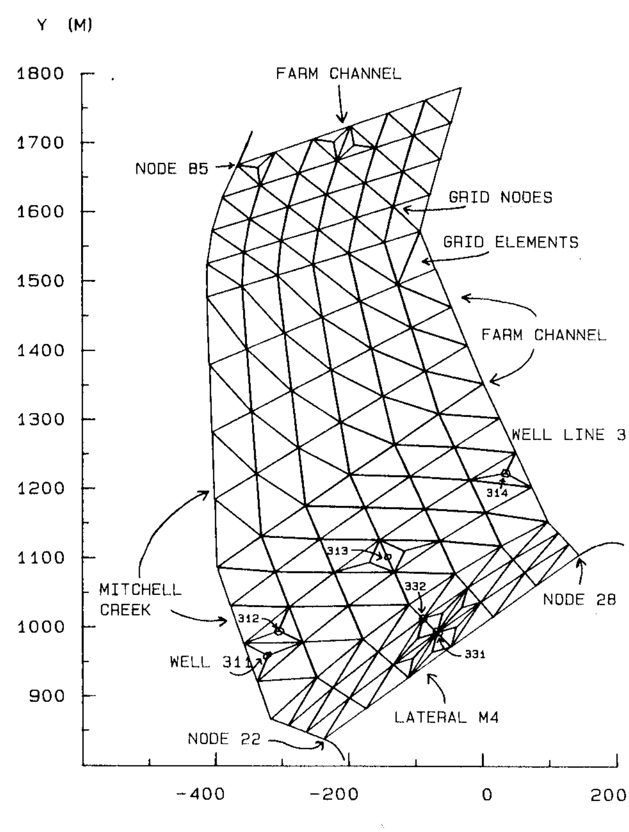

Figure 2–The finite element grid used for the simulation of Section I.

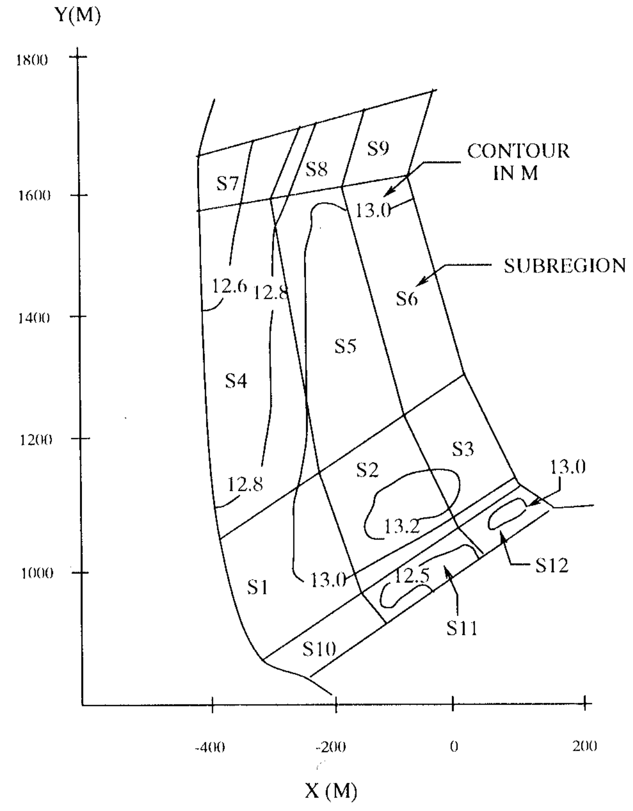

Figure 3–The soil surface elevation contours and subregions used to specify saturated and unsaturated soil inputs.

impermeable layer was a well defined clay lens that ranged from 8.2 to 8.9 m in elevation above mean sea level (MSL) and was assumed to be 8.6 m.

Observed and simulated water table elevations for well line 3 are plotted as a function of time in figure 5 for 1983 and figure 6 for 1984. Daily rainfall for 1983 and 1984 are also shown on figures 5 and 6. In some cases, the observation well was not located on a node and the simulated value was interpolated from the predicted elevations at the three nodes surrounding the well. Agreement between observed and simulated water table elevations was good for wells 311, 312, and 313 in 1983

TABLE 3. Effective lateral saturated hydraulic conductivities and soil types used for the WATRCOM simulations of section I

Subregion	Effective K* (m/day)	Soil type†
1	5.0	543
2	6.5	543
3	7.4	812
4	29.4	816
5	31.0	543
6	61.3	816
7	3.5	816
8	18.8	812
9	21.5	812
10	5.0	816
11	1.1	816
12	7.5	816
13	1.3	812

* PET determined with Jensen-Haise Method.

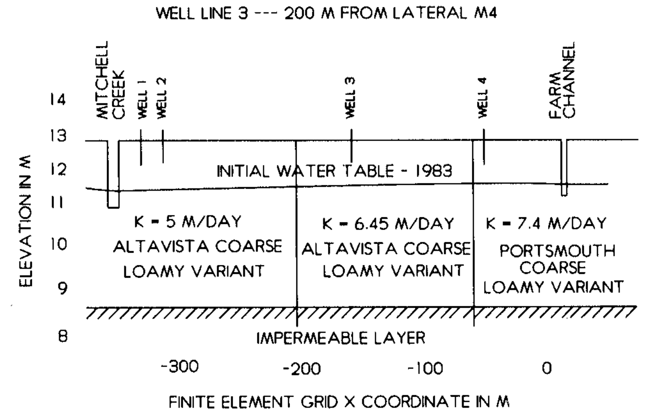

Figure 4–The transect perpendicular to Mitchell Creek at well line 3 showing some of the parameters used in the model.

(fig. 5), with average absolute errors of 0.08 m, 0.12 m, and 0.15 m, respectively. The Fabridam was lowered on day 290 in 1983 resulting in a sharp drop in the observed water table close to the channel (wells 311 and 312). The water table dropped somewhat further than predicted after

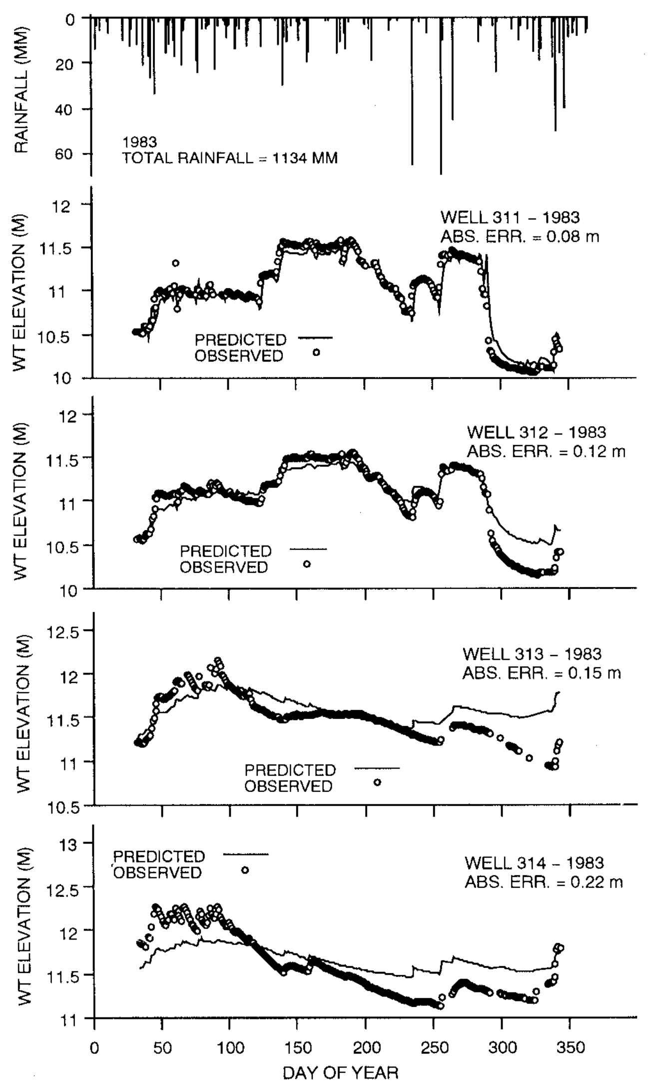

Figure 5–Simulated and observed water table elevations vs. time for well line 3 during 1983.

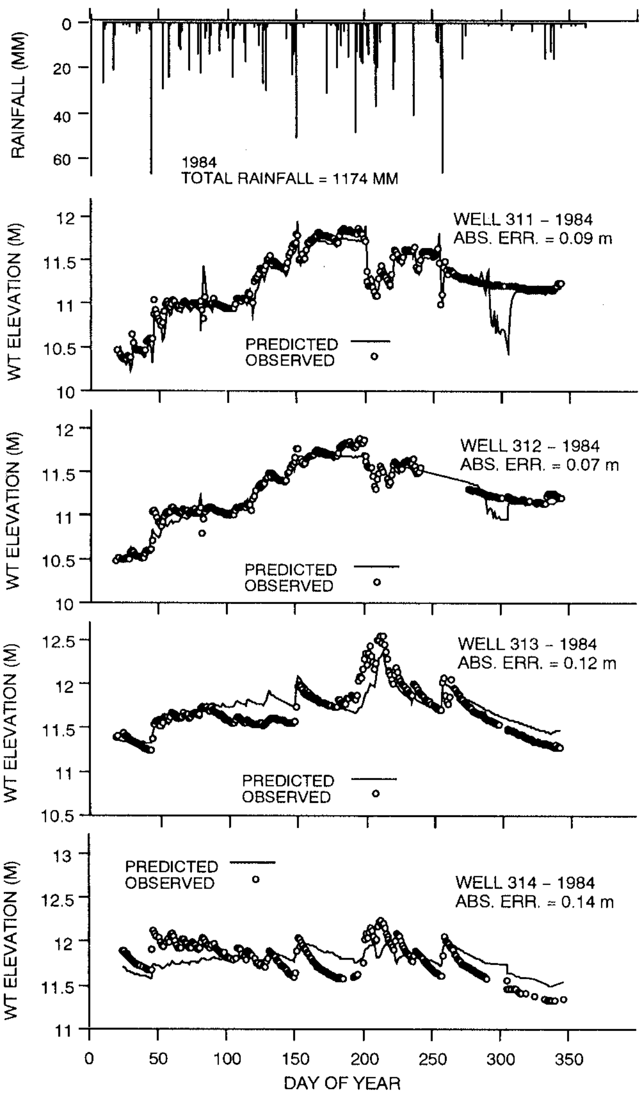

Figure 6–Simulated and observed water table elevations for wells 311, 312, 313, and 314 in 1984.

day 300, particularly in well 312. However, the observed and simulated water table elevations for these wells were in good agreement for the entire year in 1984 (fig. 6). The average absolute errors in 1984 were 0.09 m at well 311, 0.07 m at well 312, and 0.12 m at well 313.

Well number 314 was near a farm channel and the water level elevation in that section of the channel was not recorded. Assuming the water level was coincident with the bottom of the channel at 11.5 m, the simulated water table elevations were in only fair agreement with the observed water table elevations in 1983, (fig. 5). Early in the simulation, WATRCOM underpredicted the observed water tables. From day 200 until the end of 1983, WATRCOM overpredicted the observed water tables. This resulted in an average absolute error in the predicted water table elevations of 0.22 m. In 1984, the agreement between the observed and simulated water table elevations was better with an average absolute error of 0.14 m (fig. 6). Errors in the boundary conditions can have a large effect on predicted water table elevation near the boundary (Parsons, 1987). Therefore, better information on the water levels in

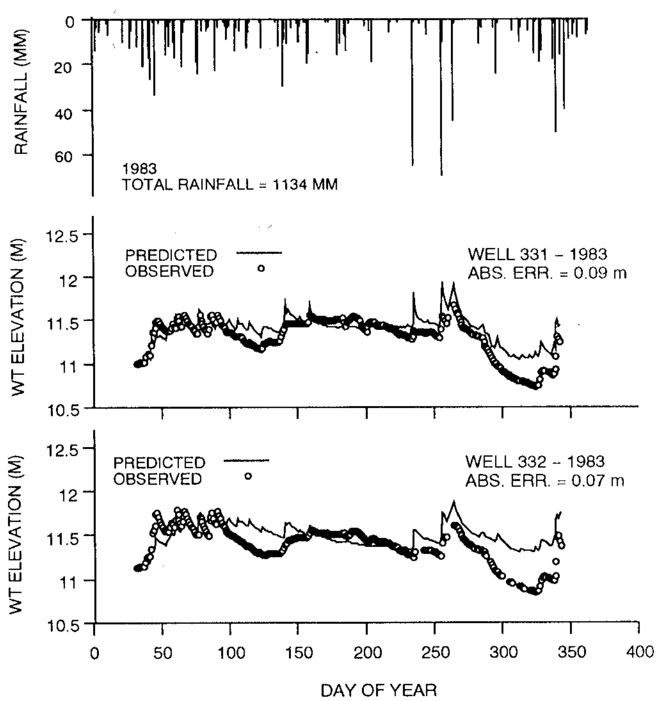

Figure 7–Simulated and observed water table elevations for the Lateral M4 transect of wells 331 and 332 during 1983.

the farm channel might have led to better agreement with the observed results at well 314.

Figures 7 and 8 present the observed and simulated water table elevations for the wells 331 and 332 for 1983 and 1984, respectively. In 1983, the agreement between

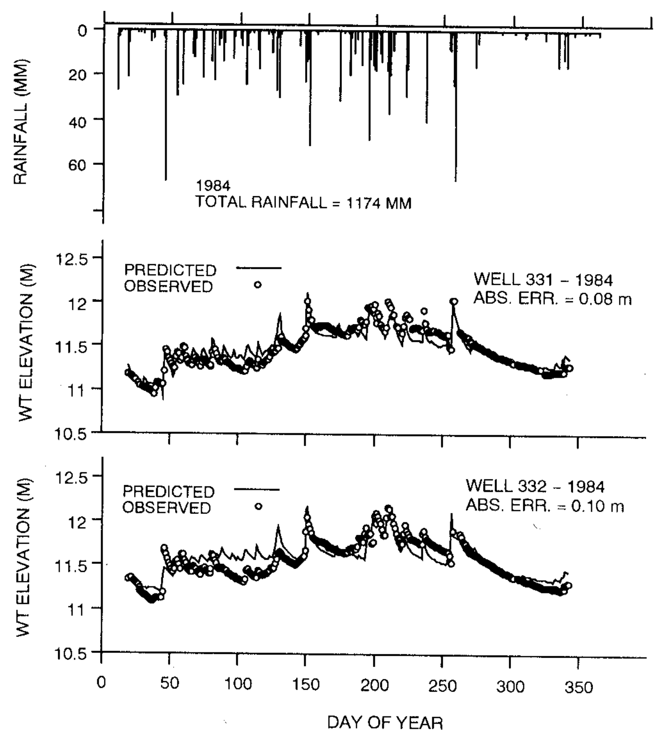

Figure 8–Simulated and observed water table elevations for the Lateral M4 transect of wells, 331 and 332, during 1984.

TABLE 4 Summary of the statistics for the simulated and observed water table elevations at each well in Section I

Year	Well code	Number of points	Average error	Average absolute error	Root mean square error	Correlation coefficient
			(m)			
1983	311	297	-0.01	0.08	0.11	0.97
	312	307	0.04	0.12	0.15	0.96
	313	265	0.09	0.15	0.18	0.67
	314	283	0.07	0.22	0.23	0.90
	331	302	0.09	0.12	0.13	0.83
	332	286	0.10	0.16	0.18	0.52
	POOLED	1740	0.06	0.14	0.17	0.90
1984	311	322	-0.06	0.09	0.13	0.94
	312	280	-0.04	0.07	0.08	0.97
	313	311	0.04	0.12	0.14	0.85
	314	261	0.00	0.14	0.16	0.49
	331	306	0.01	0.08	0.09	0.92
	332	317	0.03	0.10	0.12	0.84
	POOLED	1797	0.00	0.10	0.13	0.93

observed and simulated water tables was good for both wells with some differences between the observed and simulated water table elevations near the end of the year (fig. 7). These differences may have been due to errors in model inputs for crop root depth. Use of root depths that were too shallow during the latter portions of the growing season would have resulted in underestimation of evapotranspiration, and predicted water tables elevations that were too high during that period. Average absolute errors in the simulated values at wells 331 and 332 in 1983 were 0.12 m and 0.16 m, respectively. Agreement between the observed and simulated water table elevations was good for all of 1984 with average absolute errors of 0.08 m and 0.10 m for wells 331 and 332, respectively (fig. 8).

Table 4 summarizes the Pearson product-moment correlations, average absolute errors, and root mean square errors between the simulated and observed water table elevations for all the wells. The pooled average absolute error for all wells in 1983 was 0.14 m. The correlation between the simulated and observed water table elevations was 0.90.

For 1984, the correlation coefficient between the simulated and observed water table elevation was 0.93 (Table 4). The average absolute error in the predicted values was 0.10 m. The maximum absolute error was 0.14 m for well 314 which was near the ill-defined boundary.

Section II and III

Sections II and III (fig. 1) were combined for testing WATRCOM. This section is bordered by Mitchell Creek, Cobb Canal, and the lateral ditch, M4. Daily recorded channel water levels were assigned to these boundaries. The soil types in the area were Altavista sandy loam (coarse loamy variant), Augusta sandy loam, Portsmouth loam, and Portsmouth sandy loam (coarse loamy variant). The effective saturated hydraulic conductivities (not shown) ranged from 1.4 to 46.0 m/day with most values between 5.0 and 15.0 m/day (Parsons, 1987).

This section contains three transects of wells, lines 4, 5, and 6, each consisting of four wells. The Fabridam is located between well line 5 and 6 (fig. 1). The impermeable layer in this section was approximately 7.9 m above MSL. The soil surface elevations in the section ranged from 10.5 to 13.8 m above MSL. A finite element grid was constructed (fig. 9) and soil properties and topographi-cal parameters were assigned similar to the procedure outlined in the previous section. A detailed description of the inputs

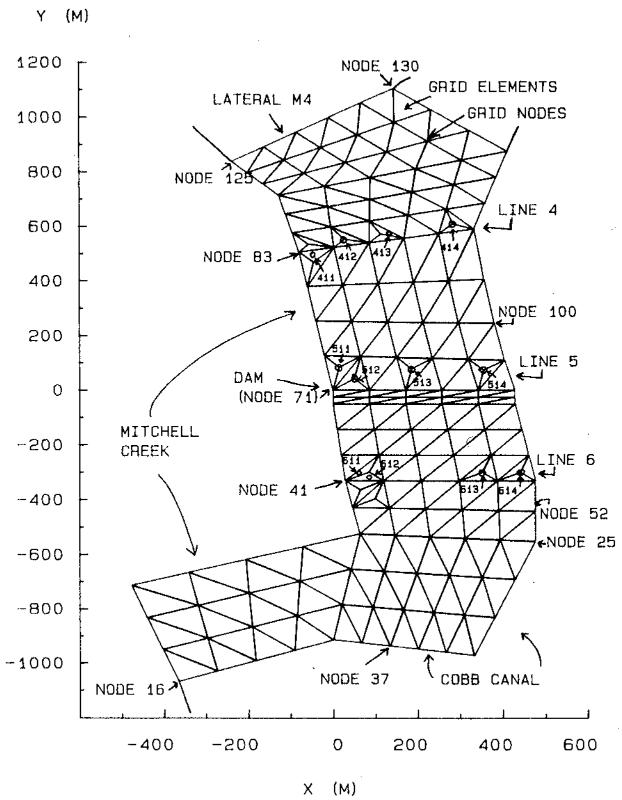

Figure 9–The finite element grid used for simulating the combined section II.

and problem setup for these simulations is given by Parsons (1987).

Table 5 presents summary statistics for the 1983 simulations of the combined section II and III. There were 3145 daily water table observations. The average absolute error in the simulated water tables ranged from a minimum of 0.05 m at well 611 to a maximum of 0.19 m at well 614. The average absolute errors for all 12 wells was 0.11 m. The root mean square error for the 1983 simulation was 0.14 m with a correlation between the simulated and observed water table elevations of 0.97 (fig. 10).

In 1984, there were 3068 daily water table elevations in section II and III. The average absolute error in the simulated water tables, 0.11 m, was the same as in 1983 (Table 5). The correlation between the observed and simulated water tables was 0.98 and was slightly better than in 1983. As in 1983, the largest absolute error of 0.18 m was obtained for well 614. The simulated water tables were closer to the observed data for the wells closer to Mitchell Creek. The minimum absolute error in 1984 was 0.05 m at well 411. The good agreement between predicted and observed water table elevations for all wells in 1984 is depicted in figure 11.

Section IV

Section IV is located on the opposite side of Mitchell Creek from sections II and III. It contains two well transects with nine observation wells: line 5 with wells 521-525 and line 6 with wells 621-624. The section is bordered by Mitchell Creek on two sides, a farm channel (Thigpen ditch), and a paved road, NC highway 1608

TABLE 5. Summary statistics for simulated and observed water table elevations in the combined section, II, and III

Well code	Number of points	Average error (m)	Average absolute error (m)	Root mean square error (m)	Correlation coefficient
1983					
411	285	0.03	0.07	0.09	0.98
412	268	0.02	0.13	0.18	0.84
413	258	0.04	0.14	0.17	0.91
414	251	- 0.07	0.10	0.09	0.93
POOLED	1062	0.01	0.11	0.14	0.93
511	268	0.06	0.07	0.06	0.99
512	248	0.06	0.10	0.10	0.96
513	279	0.07	0.12	0.14	0.94
514	263	- 0.07	0.14	0.13	0.95
POOLED	1058	0.03	0.11	0.13	0.95
611	254	0.04	0.05	0.06	0.95
612	270	0.00	0.09	0.10	0.95
613	265	- 0.05	0.13	0.15	0.95
614	236	- 0.19	0.19	0.06	0.97
POOLED	1025	- 0.04	0.11	0.13	0.98
ALL WELLS	*3145*	*- 0.00*	*0.11*	*0.14*	*0.97*
1984					
411	267	0.02	0.05	0.07	0.96
412	283	- 0.03	0.11	0.13	0.83
413	239	- 0.03	0.10	0.14	0.86
414	282	- 0.05	0.10	0.12	0.82
POOLED	1071	- 0.02	0.09	0.12	0.91
511	273	0.09	0.09	0.05	0.91
512	280	0.08	0.11	0.09	0.97
513	246	0.02	0.10	0.13	0.87
514	243	- 0.02	0.08	0.10	0.83
POOLED	1042	0.05	0.10	0.10	0.95
611	260	0.06	0.08	0.08	0.87
612	247	0.07	0.09	0.09	0.88
613	245	0.02	0.07	0.09	0.87
614	270	- 0.18	0.18	0.06	0.91
POOLED	1022	- 0.01	0.11	0.13	0.98
ALL WELLS	*3068*	*0.03*	*0.11*	*0.13*	*0.99*

(fig. 1). The paved road boundary is assumed to be a no flow boundary. Daily stream water level observations were used for the remaining boundaries. Deep borings indicated that the impermeable layer was about 7.0 m above MSL. The soil types in the area were Portsmouth loam, Conetoe loamy sand, and Altavista sandy loam. The soil surface elevation in the area ranged from 10.1 to 13.6 m above MSL and the effective saturated hydraulic conductivities (not shown) ranged from 3 to 39 m/day. The model inputs and problem setup for these simulations were described in detail by Parsons (1987).

Results of the simulations for section IV were similar to those presented for the other two sections. Table 6 presents summaries for the 1983 and 1984 simulations. Average absolute errors for individual wells ranged from 0.04 to 0.25 m. Wells closest to the main drainage channel

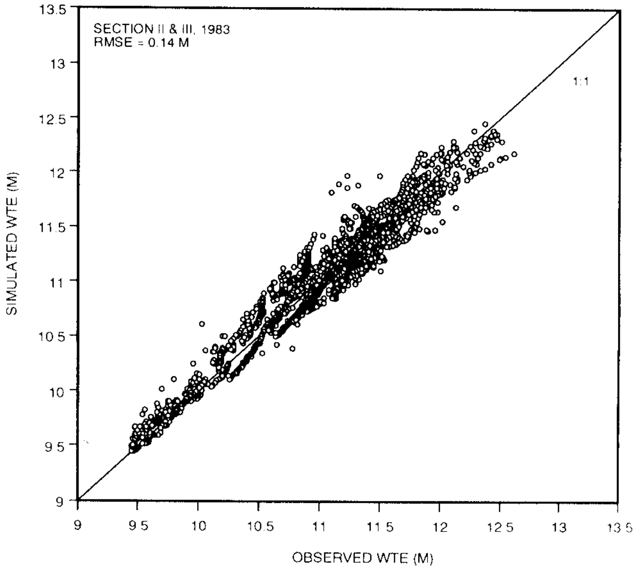

Figure 10–Simulated vs. observed water table elevation for the combined section II and III in 1983.

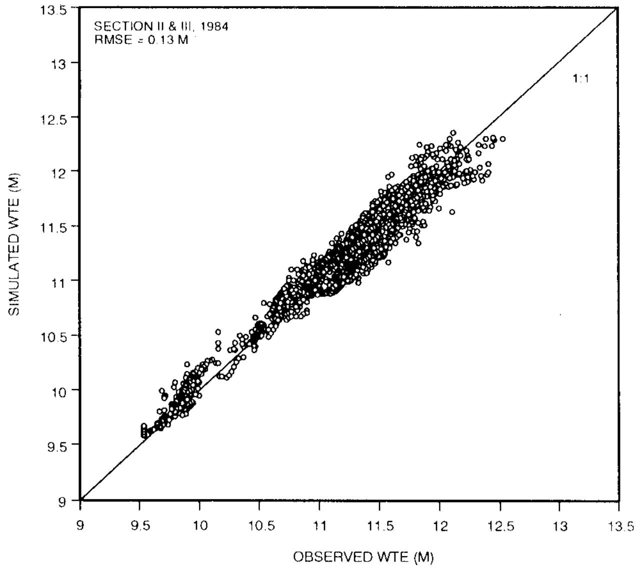

Figure 11–The 1984 simulated vs. observed water table elevation for the combined section II and III.

TABLE 6. Summary statistics for simulated and observed water table elevations in the combined section IV

Well code	Number of points	Average error (m)	Average absolute error (m)	Root mean square error (m)	Correlation coefficient
1983					
521	281	0.02	0.04	0.07	0.99
522	268	- 0.04	0.09	0.09	0.99
523	267	- 0.01	0.14	0.18	0.87
524	284	0.14	0.24	0.24	0.90
525	243	0.01	0.12	0.15	0.94
POOLED	1343	0.03	0.13	0.17	0.92
621	254	0.05	0.06	0.06	0.90
622	281	- 0.01	0.06	0.07	0.90
623	291	0.00	0.17	0.22	0.88
624	279	0.07	0.10	0.12	0.83
POOLED	1105	0.03	0.10	0.14	0.94
ALL WELLS	*2248*	*0.03*	*0.11*	*0.16*	*0.97*
1984					
521	244	0.06	0.07	0.09	0.96
522	252	- 0.01	0.05	0.08	0.96
523	277	0.05	0.14	0.16	0.76
524	248	0.19	0.25	0.22	0.50
525	240	0.03	0.10	0.11	0.78
POOLED	1261	0.06	0.12	0.16	0.86
621	247	0.09	0.10	0.07	0.87
622	247	0.07	0.13	0.13	0.59
623	252	0.02	0.15	0.18	0.44
624	209	0.18	0.18	0.11	0.50
POOLED	955	0.08	0.14	0.14	0.93
ALL WELLS	*2216*	*0.07*	*0.13*	*0.15*	*0.97*

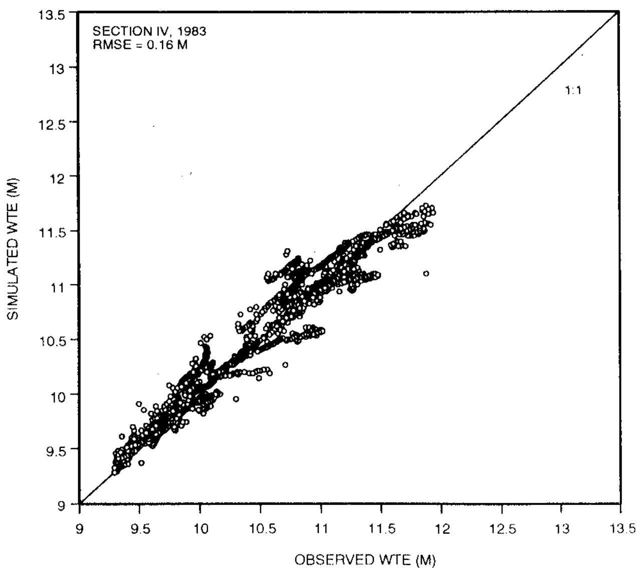

Figure 12–Simulated vs. observed water table elevation for section IV in 1983.

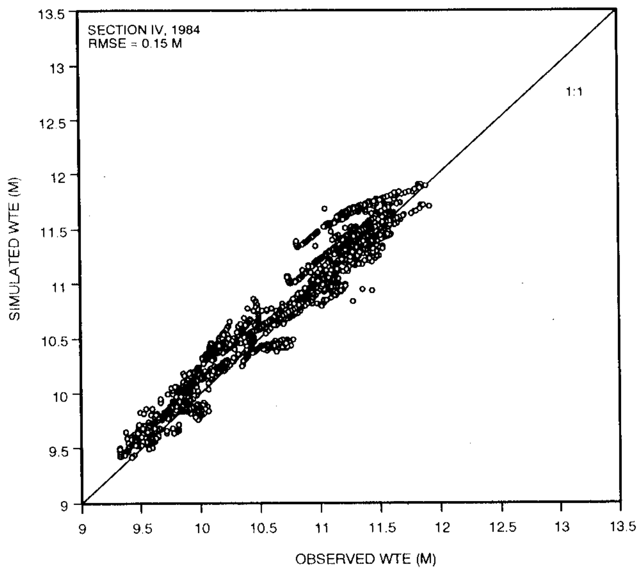

Figure 13–The 1984 simulated vs. observed water table elevation for section IV.

(Mitchell Creek) yielded the smallest average absolute errors, while those farther away had larger errors. There were 2248 and 2216 daily water table observations in 1983 and 1984, respectively. Overall, average absolute errors in the simulated water table elevations were 0.11 m for 1983 and 0.13 m for 1984 for all wells in section IV. Simulated water table elevations vs. observed values for 1983 and 1984 are plotted in figures 12 and 13, respectively. The correlation coefficient between the simulated and observed water table elevations was 0.97 for both years.

Summary and Conclusions

Predicted water table elevations were compared to observed data for three sections of a research watershed near Tarboro, NC. Field observations from a total of 27 water table observation wells for 1983 and 1984 were used to test the reliability of the WATRCOM simulation model. Each of the three sections was divided into subareas according to the soils map and input parameters for the model were estimated based on the soil type of each subarea. Field observations of saturated hydraulic conductivity were used with the soil type information to assign the inputs for subareas of each section. All simulations were based on measured field parameters and no calibration simulations were conducted to optimize model parameters to fit observed data.

There were 14,481 daily observations of water table elevations used in testing the model. The minimum average absolute error in the simulated water table elevations for one section year was 0.04 m and the maximum was 0.25 m. The average absolute errors for all wells on all sections was 0.12 m. Correlation coefficients between simulated and observed water table elevations for all wells on each section were all greater than 0.90 and in most cases greater than 0.97. Since the model input parameters were estimated on a subregion basis rather than at each simulation point in the area, the model performance is considered acceptable. These results indicate that the model can reliably predict water table response to channel water level management. Thus, the effects of managing channel water levels on water table elevations and water conservation on a watershed scale can be evaluated by using the WATRCOM simulation model. Hydraulic soil properties must be determined for the major soils in the watershed and extensive field, crop, and climatological data are required. However, the cost and time required by this approach is a small fraction of that required to experimentally determine the effects.

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